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A MYSTERIOUS TYPE OF LOW-DRAG SHAPE

De Kang

When one is out in a windy rainstorm and walking with his umbrella up, it is a very tiring thing to do; wearing a rain coat is much better (Fig. 1). The reason for this is very clear to everyone; this reason is that, because of the fact that the area of the umbrella which catches the wind is increased after it is put up, the drag which is exerted on it is also increased. Because of this fact, it makes no difference if one is talking about aircraft, automobiles or steamships, in order to make their speeds somewhat faster, design personnel always need design types which cause the area which catches the wind to be as small as possible. This is particularly true of aircraft design. In the case of such designs, it is not only necessary to make the shape or external form smooth and flowing; it is also necessary to design all the various components which are in the path of the air flow as thin as possible and as fine or small as possible, so as to present to the air flow as unobstructed a line as it can have.

In Fig. 1 we see presented two types of form or shape; their chord lengths (b) are both the same. However, the corresponding thicknesses of the two of them (that is, the largest thickness c/b) are not the same. The top one is 53.6%, and the bottom one is 31%. In such a case, if one makes a comparison of these two shapes, which has the greater wind resistance or drag?

The process of experimentation and calculation demonstrates that, even though the bottom form which looks like a parachute from the side certainly does have a wind catching area which is much larger than that of the ordinary wing shape, surprisingly, the wind resistance of this form is still somewhat smaller.

Why is this? On the face of it, there is something in this anomaly which does not stand to reason, but, for all of that, it is a fact. Last year, when some American scholars in the field of aerodynamics came to China to lecture, they introduced, among their works, their masterpiece----- a type of low-drag shape and the mystery presented by it.

HOW THE PROBLEM CAME UP

When an aircraft is in flight in the air, all the parts which are exposed to the air (that is to say, the skin) all are capable of producing a rubbing against the air, and this produces friction. As far as the wind drag which we have spoken of goes, a very large part of it comes from precisely this kind of friction. Obviously, if one is thinking of how to take a step forward in raising the speed of flight for aircraft, one very important measure would be precisely to come up with a design method which will decrease these frictional forces. Taking the shape or form of an aircraft and designing it so that it achieves a smooth and flowing line, taking some of the exposed parts (such as handles, racks, engine pods and so on) and making them somewhat smaller and somewhat thinner are all methods which are capable of reducing the frictional forces. However, there are, in the final analysis, passive or negative methods. Their power or effectiveness is limited, and, sometimes, one even reaches the point at which he is obtaining one benefit at the expense of acquiring another disadvantage. This causes other problems. For example,

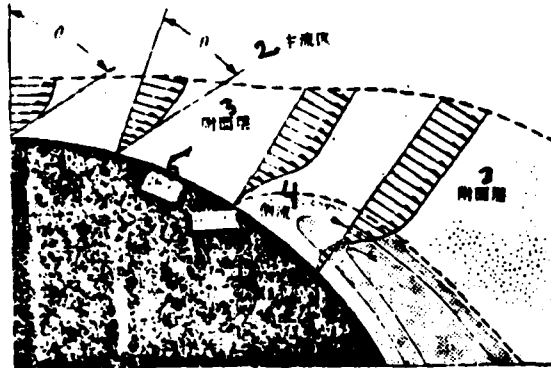


Figure 2

2. The Area of Main Flow 3. Boundary Layer
 4. Inverted of Counter-Current Flow 5. (Unreadable)
Surface.

if one designs the wings of a transport plane too thin, then, in order to satisfy the requirement for strength, the weight of the structure must be greatly increased; moreover, the relative deficiencies in rigidity can cause the occurrence of wing shaking and other similar problems, etc., etc.....

Is it possible to find a method which is even more effective and which provides bigger advantages with smaller disadvantages? This is just one of the topics which have occupied the meditations and intense thought of specialists in aerodynamics for a long time, and it is a topic which is still under investigation right up to today.

Below we will introduce one of the relatively successful methods of attaining these objectives.

BEGIN WITH A DISCUSSION OF BOUNDARY LAYERS

We know that, when an air flow passes over the surface of an object, due to the action of viscosity a very, very thin boundary layer will appear. The boundary layer is the basic

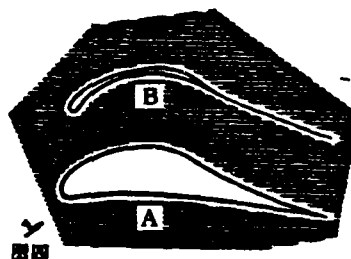
source for the production of frictional forces. In order to reduce the frictional forces within the boundary layers, people have carried out intensive research. This research has discovered that, even if the speed of the on-coming flow, and its density as well as the form or shape of the surface involved are kept constant, the speed distributions for various places in the boundary layers will still have very large differences between them. What is particularly interesting is the fact that, if we make a cross-section diagram of the speed distribution curve for a point on the surface of this cross-section, the one obtains an included angle θ . In such a case, it has already been theoretically proven that the frictional forces between a surface and an air flow have direct proportion with the angle θ ; the smaller the angle θ is, the smaller are the frictional forces for the point involved or, when the reverse is true, the larger the frictional forces will be. In many articles on aerodynamics, we see the concepts of "laminar flow boundary layers" and "turbulence flow boundary layers". Speaking in these terms, one may say that the angles θ for various places in a laminar flow boundary layer are all relatively small. It follows from this that the total frictional forces are also very small. The angles θ for various places in turbulence flow boundary layers are all relatively large, and it follows from this that in this case the total frictional forces must then also be much larger. Of course, this sort of statement is very crude and shallow; in fact, several important characteristics which are related are still a mystery to this day.

ONE OF THE DANGERS WITHIN BOUNDARY LAYERS

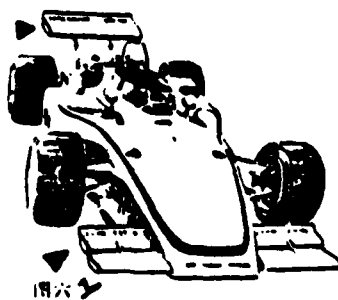
Now, if we follow a certain boundary layer flow as it flows across a curved surface, we will meet with, if we keep our eyes open, a certain number of rather interesting phenomena.

First of all, we know that, no matter what type of frictional force one is dealing with, in general, its effect is to block or hold back the motion of the body that gives rise to it. It follows from this that, when a gas flows forward, it is always at the

expense of the constant consumption of kinetic energy in order to overcome the frictional forces of the surface. This purpose continues to the point where it causes the speed distribution curve for various points within a boundary layer to gradually attenuate, which is the same thing as saying that the angle θ gradually gets smaller. Obviously, we are going to reach a certain point (point S) at which the speed distribution curve is attenuated to the point where the angle θ is zero. This means that the layer of gases which adheres most closely to the surface has already lost the energy necessary to continue moving forward. Because of this fact, when the whole boundary layer does flow forward, those gases which have no energy left will inevitably "flow backwards" bucking the flow. This is an extremely dangerous situation. The reason for this is that the appearance of backward or counter-current flow fundamentally shakes the forefront of the entire boundary layer causing it to flow away from the surface of the object. This is what is called a "separation" phenomenon.



1. Fig. 4



1. Fig. 6

Comrades who have even a little common knowledge of aerodynamics all know that the appearance of a "separation" phenomenon appears on the wing of an aircraft, then, it can lower the lifting power of the wing and cause a sudden increase in drag. If it occurs on the aircraft itself, it can often give rise to several such dangerous phenomena as shaking, rolling and even cork-screw type spinning. Because of this, in the design of aircraft or various other kinds of aerodynamic designs, separation phenomena of this type are generally avoided as much as possible.

Personnel working in the field of aerodynamics call the S point the "point of separation", and they have thought of several aerodynamic methods for avoiding the occurrence of this type of phenomenon or for at least delaying its occurrence.

THE INTELLIGENCE AND COURAGE OF SCIENCE

Because of the fact that, before the airflow comes to the point of separation, the boundary layer is entirely "parallel flow" and it is only after passing this point that one gets the appearance of "counter-current" flow, it follows that, aerodynamically speaking, one could also call this point the "point of intermediate nature." The interesting thing is that, because of the fact that the angle θ at this point is equal to zero, therefore, the friction is also equal to zero. It is precisely because this point of intermediate nature or neutral point has this important characteristic of zero friction that a specialist in aerodynamics came up with a courageous proposition: that is, could it be possible to find a shape with such a form that, when a current of air flows over it, every point in the boundary layer is a neutral point? If this could be done, then, when an air current passed over such a form, would the friction at each point not also be zero?

If it is actually possible to find this type of shape and to make it into the wing of an aircraft, then, in such a case, it must certainly be small enough to be very welcome indeed.

What is even more wonderful is that, because of the fact that every point in this type of flow is a neutral point, even if these points seem to be on the verge of exhibiting separation phenomenon, in reality, all the points throughout the flow will still be in a neutral state. Moreover, there will be no occurrence of counter-current flow nor will there be any separation anywhere. In this type of flow, all traces of the "area of separation" will have disappeared.

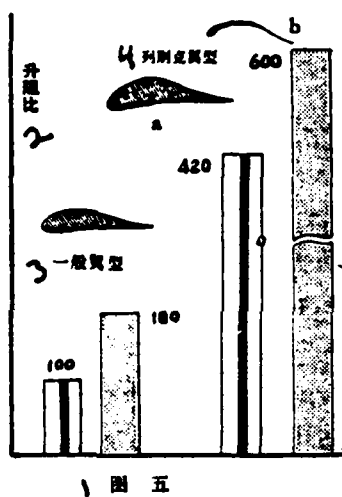


Fig. 5

1. Fig. 5
2. Lift-drag Ratio
3. Ordinary Wing Shape.
4. The New Wing Form

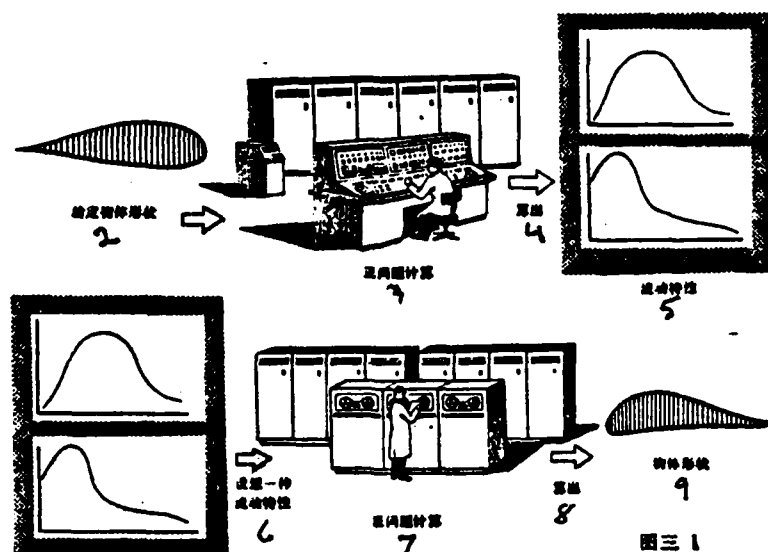


Fig. 3

1. Fig. 3 (sic) 2. The Shape of an Object 3. Normal Problem Calculations 4. Output Calculations 5. Flow Characteristics 6. A Proposed Type of Flow Characteristic 7. Recalculation of the Problem 8. Output Calculation 9. The Shape of the Object

This seems too marvelous to be true. Can this type of shape really be found?

Specialists in aerodynamics, aided by such modern tools as computers, have begun to search out the secret of the flow form described above.

UNEXPECTED SUCCESS

In aerodynamic calculations, if one is given the shape of an object and is going to figure out the pressure distribution (or the speed distribution, say) for an air flow as it passes over the object, then, we call it a "normal problem" calculation. On the other hand, if we first imagine a pressure distribution for a type of flow and then try to figure out the shape of an object which has flow characteristics which satisfy the distribution (it can also be for a speed distribution), then, we call this a "reverse problem" calculation (Fig. 3). Compared to "normal problem" calculations, the "reverse problem" calculations have much more intense interest to the investigator; this is due to the fact that normally it is either not possible to figure out a thing that will fit the conditions or the physical shape which is calcu-

lated is so strange that it is of no practical value.

However, the form which has the shape we have been talking about genuinely worked out.

Please take a look at Fig. 4 which is a representation of two forms which were figured out by a specialist in aerodynamics. He began by assuming the existence of a flow field of the following kind: that is to say, a flow field in which the forward section is a laminar flow form, and the after section is a flow form of the type we have been discussing. The frictional forces for both these flow forms are very small, particularly for the latter. Because of this fact, the total drag values for both of the two type of forms which he figured out are low enough to be pleasing to anyone.

Generally speaking, the lift-to-drag ratio for binary wings is very good if it reaches 100; very seldom does it ever exceed 180. However, the A wing form in the figure not only reached 420, but the B-type wing form actually reached as high as 600 (see Fig. 5). These sorts of ratios are extremely difficult to obtain. At present, the characteristics of the A-type wing form have already been completely verified by wind tunnel experimentation; moreover, it has also been successfully used in competition racing cars (Fig. 6), in the design of the blades on special types of fans (Fig. 7) as well as in applications on man-powered aircraft. Although the $\frac{8}{2}$ -type form is a shape which theoretically has a thickness which approaches zero, some people have simulated it in its external form in order to make sails for ships (or umbrella wings for aircraft) and, in all these applications, the results which have been achieved have exceeded all expectations.

RETURNING TO THE BEGINNING

Now it would be perfectly natural for everyone to imagine that the low-drag shape with the large area catching the wind but with the small amount of wind drag, as it is shown in Fig. 1, is designed according to the flow form we have been talking about. This is completely correct. When an air flow passes over this

shape, there is a laminar flow form before the flow gets to the turning point and a flow form of the type we have discussed once that point is passed. Because of this fact, when the Reynolds number is approximately 10^7 , the coefficient of drag is only 0.0077; moreover, there is no separation on the surface. The most outstanding advantage of this type of shape is "coarseness"; because of the fact that, when this shape is used to make pillars or braces, it has very good structural characteristics (rigidity is good and strength is also good); these applications also have very good low-drag characteristics. This is extremely useful from the point of view of aerodynamic design. Concerning the satisfying of several simultaneous structural requirements, the aerodynamic characteristics of components such as aircraft wing supports, racks for hanging things on the outside of an aircraft as well as wind blocks and rods used in wind tunnel tests, in the past, have always exhibited the principle that it is necessary to pay the price for satisfying aerodynamic requirements at the expense of the structures; however, the type of low-drag shape which we have been talking about is capable of achieving a satisfactory treatment of both aspects. Besides this, it is also capable of being used for the shape of special types of fuselages or ship bodies as well as the shape of special types of structures. However, the thing that is really regrettable is that we

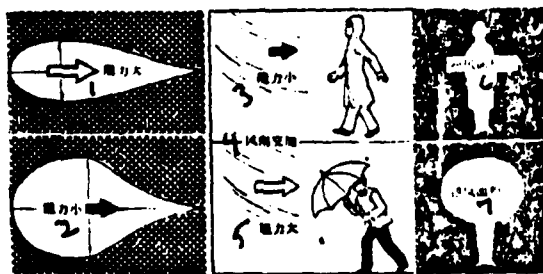


Fig. 1.

1. Fig. 1 This is an axial flow fan based on engineering designs; the cross-section of its blades employs the wing form which we have been discussing. This type of fan can be used as the fan for climate control units or duct systems, and so on.

1 - thin; 2 - thicker; 3 - less; 4 - drag; 5 - greater; 6,7 - illegible.

have still not seen the application of this type of shape to modern types of aircraft. On the face of it, it seem that there are still definite difficulties which must be overcome in order to reach this objective; this must wait on further advances in research and investigation.

ILLUSTRATIONS: LI XIONG

THE RESURRECTION OF THE SWEPTFORWARD WING AIRCRAFT

Xiong Wei

Several years ago, the American Department of Defense cancelled the order for the B-1 bomber; this caused the Rockwell International Aviation Company to be placed in a difficult situation. Most of its engineers, machinists and so on, resigned or switched over to other companies in large numbers. Many of the operations under the Rockwell name had to change their markets, undertake the production of the components for the bomber, and do the best they could to combine these components in order to form parts for aircraft which Rockwell could use.

Just at the time when Rockwell was hitting its low ebb, President Carter suddenly announced a plan for the development of and research into sweptforward wing fighter planes.

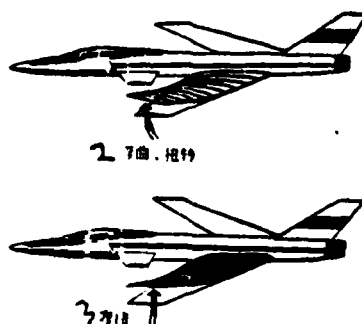


Fig. 5

1. The version of the top is a sweptforward wing made of ordinary materials, the version below is a sweptforward wing made of composite materials. 2. Bending and twisting. 3. Bending.

In the last few years, Rockwell, General Dynamics and Grumman Companies have begun research into sweptforward wing aircraft.

To tell the truth, sweptforward wing aircraft are not completely new things.

More than thirty years ago, in fact, in the last stage of the Second World War, Hitler test produced the "Rong-Ke 287" jet bomber (Fig. 1); this aircraft possessed a 15 degree (some say a 12 degree) sweptforward wing angle, and, before it was knocked out by the Allied bombers, it had already been test flown several times; it was said finally to have been captured by the Soviet Union. The Germans understood that the sweptforward wing has very good low-speed aerodynamic characteristics. Again, in the later "Han Sha HFB 320" jet aircraft (Fig. 2), this type of wing was also employed with the wings installed toward the rear of the aircraft which allows the fuselage to be designed in a wider and more open fashion.

After the war, the predecessor of the Rockwell Company, North American Company, designed a sweptforward wing aircraft called the "Mustang" fighter. Several decades later, the sweptforward wing aircraft appeared in their research plans again in a new form; this was no accident, but was the result of an entirely objective development decision made on the basis of scientific and technological factors. Today, new materials and new technologies which have widespread applications in aviation have spelled a rebirth for the sweptforward wing aircraft.

If the sweptforward wing aircraft now has a chance to reappear in the skies, it is natural for people to ask, "Why didn't sweptforward wing technology receive more atten-

tion before now? Why is it only now being developed?"

EXCELLENT AERODYNAMIC CHARACTERISTICS

When people see a sweptback aft-positioned wing aircraft flying through the skies, they should get used to it and not feel that it is strange. It is possible to say that the sweptback aft-positioned wing aircraft is one of the most universal types of aerodynamic lay-outs or forms; in the field of high-speed and relatively high-speed aircraft, missiles and even spacecraft, it occupies an almost completely dominant position; it is everywhere. Its development has appeared in order to satisfy the requirement for increased speed. In high-speed flight, the drag of this type of wing is clearly much smaller than the drag for a normal aircraft wing; this fact assures this type of wing of a quick development; however, at present there seem also to be a certain number of problem areas, among them the fact that when the wings of an aircraft are sweptback, a lateral flow is produced along the wings, which produces a boundary layer and a thrust accumulation in the area of the wing tips, influencing the production of lift. At the same time, this condition causes the aircraft loading to be concentrated along the forward edge of the wings, and, when the angle of attack is great, this causes the appearance of a separation phenomenon on the leading edge of the wings of the aircraft.

On the other hand, a sweptforward wing, under the same type of conditions, does not have these shortcomings. Because of the fact that the sweptforward wing and the sweptback wing are opposite from each other, one will not see this type of situation with the sweptforward wing, i.e., the occurrence of separation phenomena and the excessive loading of the forward edges.

Experimentation and research also demonstrate that, if one employs a canard configuration with a sweptforward wing, then it is possible to produce excellent flight results; the reason is that during periods of low-speed flight the canard wings are capable of coordinating or harmonizing relatively weak air currents, maintaining the stability of the aircraft. Of course, canard wings have the same types of results when employed with sweptback wing aircraft.

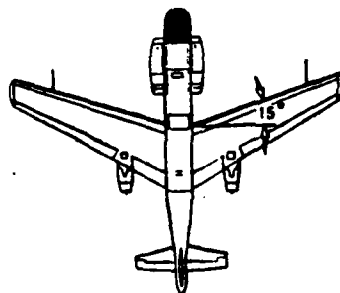


Fig. 1: "Rong Ke" 287



Fig. 2: "Han Shaw" 320

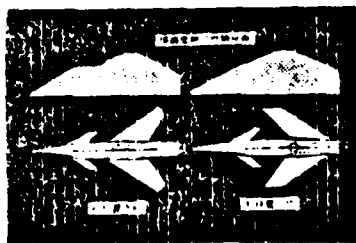


Fig. 3: "Han Sha" 330

When aircraft are in supersonic flight, they are capable of producing very large amounts of shock wave drag. Moreover, it is relatively easy for sweptforward wing aircraft

to satisfy the requirements of the area rule. This type of wing arrangement causes the cross-sectional area distribution of an aircraft to be changed into a relatively smoother shape (see Fig. 4), and this is useful in the reduction of drag during flight.



Fig. 4: Distribution of cross-sectional area.

The lifting power of sweptforward wing aircraft is also larger than that for similar types of sweptback wing aircraft. Because of this, this type of aircraft only requires a very short runway in order for it to be able to take off and land (compared to sweptback wing aircraft of similar types.) These are all aerodynamic advantages which are extremely hard to find.

Besides this, another point which must be considered is that the center of gravity of aircraft with sweptforward wings is over the center of the fuselage. Because of this fact, assuming that conditions will permit, reductions and increases in the load of the aircraft do not change its good flight stability characteristics.

THE USE OF COMPOSITE MATERIALS

The aerodynamic characteristics of sweptforward wing aircraft are better than those of sweptback wing aircraft; and if this is so, why are people only now taking a serious look at it? The main reason is that there were previously no

materials capable of being used in this sort of application at the high speeds required.

Concerning materials, this problem is related to the problem of divergence in aerodynamic elasticity. When aircraft are in flight, due to the fact that the weight of the aircraft as a whole cause the wing tips to bend up, there is an elastic deformation in the wings; this situation will also cause the form of the wing to develop a twist. When sweptback wing aircraft experience an increase in the angle of attack, the twist in the wing reduces the angle of attack, and there is a tendency for this reduction to keep the aircraft from lifting its nose; this causes the aircraft to return to its original attitude of flight; this is called aeroelastic recovery.

In the case of sweptforward wing aircraft, when there is an increase in the angle of attack, the twist in the shape of the wings is just the opposite, and such an increase in the angle of attack causes the aircraft to have a tendency to life its nose, which is called aeroelastic divergence (see Fig. 5).



Fig. 5

Because of this, when sweptforward wing aircraft are in flight, if control is not exercised in just the right way there may be a possibility of bending or even breaking of the wings; this makes sweptforward wing aircraft extremely dangerous when they are constructed from the general run of materials.

In order to overcome this disadvantage, it is necessary for the wings of the aircraft to achieve increased rigidity. Doing this requires making the wings of heavier structure, which necessarily causes the weight of the aircraft to increase, causing the supposed advantages of the sweptforward wing aircraft to pale considerably. This is the main reason why sweptforward wing technology could not be applied for such a long period of time.

However, by employing new advances in composite materials, it is possible to successfully control the harmful effects of aeroelastic divergence on sweptforward wing aircraft; this verifies the possibility of having aircraft wings which are capable of having excellent rigidity and strength in their designs; it is said that the idea for taking these types of advanced new materials and using them in sweptforward wing aircraft was first thought of by a Colonel in the U. S. Air Force, whose name sounds like Cao Lian.

Not only do composite materials reduce the weight of components in which they are employed, they also have high rigidity and strength characteristics; the key to using them to build wings for aircraft is the problem of direction, distribution and thickness of fiber layers. If we are speaking about sweptforward wing aircraft, the rigidity of such materials against twisting makes for important applications. This type of characteristic not only prevents aeroelastic divergence, it controls the loading distribution of the wing;

moreover, it also has a great influence on both the moment of flex at the base of the wings and the shape of wing deformations.

The advent of composite materials caused personnel involved in the work of aircraft design to open the door to the employment of sweptforward wings; it was no longer necessary to be concerned about the increase in weight caused by the problem of aeroelastic divergence, and this gave a new life to the use of sweptforward wing technology.

AMERICAN RESEARCH INTO SWEPTFORWARD WING AIRCRAFT

Concerning the research of the three American companies we have been discussing in sweptforward wing technology, although this research has only been going on for a few years, the work of basic evaluation has already been finished. This research demonstrates that sweptforward wing technology has the potential for development; this configuration has given excellent aerodynamic performance during flights at transsonic speeds; this is a particularly important characteristic when one is considering high-performance fighters. For example, if one takes the basic design for the F-16 aircraft as a foundation and changes it into a swept forward wing aircraft, not only is it possible to increase its flight capabilities, it is possible, moreover, to reduce the dimensions of its fuselage; this makes it possible to lighten its weight by 25% and reduce production costs. Last year, the research work entered a second phase, that of using sweptforward wing models of aircraft for transsonic and supersonic wind tunnel experiments.

At present, the General Dynamics Company has already designed a sweptforward wing model of the F-16 aircraft (see Fig 6); preliminary wind tunnel experiments demonstrate that

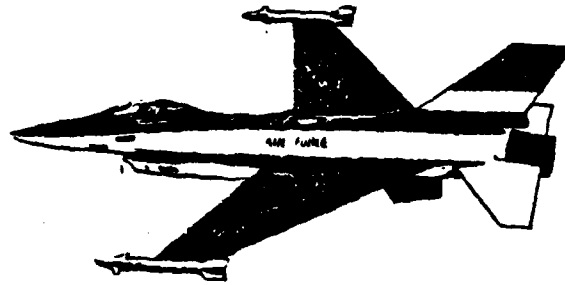


Fig. 6: Sweptforward wing version of the F-16.

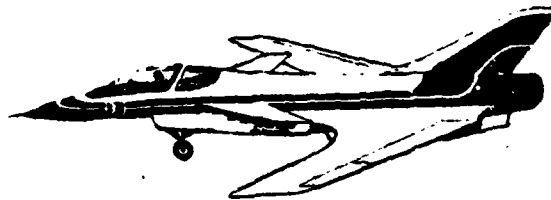


Fig. 7: Model of a sweptforward wing aircraft.



Figure 8: Full scale model of sweptforward wing fighter plane.

the sweptforward wing version prevents aerodynamic separation very well (the wing tips lose their speed last) and the operational characteristics for large angles of attack are relatively good. If one makes a comparison with the sweptback wing version of the F-16, under otherwise similar conditions, the use of the sweptforward wing is capable of reducing drag

from 10% to 25%.

The Grumman Company has already made flight tests of a remote control model of a sweptforward wing aircraft (see Fig. 7). Rockwell International Company has also built a large, full-scale model of a sweptforward-wing fighter plane (see Fig. 8).

At present, the U. S. Department of Defense has already given out to these three companies \$1,000,000 in contract money to do this type of research, and the work is going smoothly. Concerning the flight testing of sweptforward aircraft, it is hoped that it can be carried out within the decade of the '80s. It is possible that the people of the future will meet up with this new type of sweptforward wing aircraft; however, this will require a definite expenditure of time as well as the necessity for a lot of work.

ILLUSTRATIONS: XUE ZHI-GUANG

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